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ABSTRACT

Many science educators are concerned with students' ability to understand science as a process and with their conceptions of scientific knowledge. Preliminary work has shown that the use of a model organizer can result in student perceptions of improved understanding, but the reason for this effect is not known. This research was undertaken to determine whether students' conceptions of models and the model building process could be useful as an organizer for understanding scientific knowledge and process. Subjects were 687 undergraduate general biology students at a comprehensive southwestern university. These students were asked to respond to two similar sets of six statements referring, respectively, to models and model building or scientific knowledge and process. Responses were reduced to a manageable number of descriptive propositions and analyzed. Results indicated that relationships describing the artificial nature of models could be useful if transferred to the students' conception of scientific knowledge. Such an organizer could be counterproductive in other areas, however, if instruction was not given to expand students' awareness of the full range of models and the process of model-building. Students' knowledge of models was less extensive than might have been expected or desired for individuals at this educational level and this points up a possible weakness in the current science curriculum. (Author)

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Student Knowledge of Models and Science: Some Findings and Relationships

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Abstract

Many science educators are concerned with students' ability to understand science as a process, and with their conceptions of scientific knowledge. Preliminary work has shown that the use of a model organizer can result in student perceptions of improved understanding, but the reason for this effect is not known. This research was undertaken to determine whether students' conceptions of models and the model building process could be useful as an organizer for understanding scientific knowledge and process. Subjects were 687 undergraduate general biology students at a comprehensive southwestern university. These students were asked to respond to 2 similar sets of 6 statements refering, respectively, to models and model building or scientific knowledge and process. Responses were reduced to a manageable number of descriptive propositions and analyzed. Results indicate that relationships describing the artificial nature of models could be useful if transfered to the students' conception of scientific knowledge. Such an organizer could be counterproductive in other areas, however, if instruction is not given to expand students' awareness of the full range of models and the process of model-building. Students knowledge of models was less extensive than might be expected or desired for individuals at this educational level and this points up a possible weakness in the current science curriculum.

Introduction

Recent innovations in the field of science education have placed little emphasis of the search for a better and more revealing definition of science itself. The purpose of this paper is to present a definition which appears to have considerable explanatory value and which may be more consistent with current views of knowledge than those which exist in most texts. Preliminary research results which indicate its potential effectiveness will also be presented.

The rationale for developing a new definition is the belief that science processes and concepts, while important, should not be learned in isolation from the general paradigm which guides the discipline. Intense concern for the development of concept and process skills without a concommitant concern for the development of a focal purpose may lead to an empty subject-matter competence; an education creating narrowness in scientists and citizens who must be broadly literate in science. An important objective of science education is to develop an understanding of the nature of science and the knowledge it produces (Clark & Holler, 1986; Fensham, 1983; Miller, 1984; Wagner, 1983), a need reflected in the goals published by the National Science Board Commission on Precollege Education in Mathematics, Science and Technology: help children learn to formulate questions, seek answers through observation and interpretation, problem-solve, think critically, and judge the worth of articles presenting scientific conclusions (Coleman & Selby, 1983).

Both content and process skills are necessary, but not sufficient to achieve these ends. As consumers rather than practitioners, students need to develop a conceptual structure through which they may assess the legitimate and illegitimate claims of science. Gould (1987) points out that Supreme Court Justice Scalia's dissent from the decision striking down Louisiana's Balanced Treatment for Creation-Science and Evolution-Science Act of 1981 is based in part on his failure to understand the limits of science. Scalia's opinion, based on an erroneous conceptualization of evolution as the study of origins rather than processes, illustrates the danger of ignorance in high places.

Perhaps Scalia would not have made such an error had he received more training in content and process skills. Still, there is no way of knowing, and research by Barber (1961), Mahoney (1979), Merton (1969), Roe (1961) and others demonstrates that well-trained professional scientists are quite capable of similar misunderstandings. It must also be remembered that citizens who work or intend to work in nonscientific fields may have neither the time nor the interest to pursue scientific study in depth. To a large

degree, the understanding needed to make informed judgements must be based on knowledge of the comprehensive paradigm that governs the actions and products of science, and thus forms the basis for understanding intelligent arguments in a number of areas. There seems to be a distinct need for a third component in science education: the development of a framework within which to fit the role and process of science.

One way to address this need is to attend to the definition of science itself. Like any complex activity, science can be conceptualized in many different ways, but a good operational definition should specify its process and product across many fields, including the social sciences; should say what is to be observed; should assign clear and precise meanings to important concepts; and should fit into a consistent theoretical framework (after Kerlinger, 1973; Sellitz, Wrightsman and Cook, 1976). It should, in a sense, define the paradigm. Comprehensive definitions of this sort are clearly lacking in most science textbooks, and some curriculum development efforts. Those which exist often give an impression of certainty, authority, and rigorous adherence to logic which does not reflect the way science actually operates. If students are not given the opportunity to structure their knowledge according to an explanatory paradigm, then it is unlikely that other efforts to develop their capacity for critical thinking or instill in them a cautious view of human knowledge will be fully successful.

Providing a comprehensive working definition with specific educational purposes is one way to overcome this problem. A definition will be most effective if it is built upon a system which is familiar, or should be familiar, to the learner. The definition here proposed was developed through recognition of fundamental parallels between model-building and scientific research which appear to reflect the essence of scientific process (Gilbert, 1987a). It reflects the belief that knowledge itself is a model, rather than a reality, upon which humans base their actions. The working definition that follows is from this assumption is that science is the process of constructing predictive models, a conceptualization that is grounded in the ideas of Kuhn (1970).

This idea is not new, although its encapsulation into an operational definition appears to be. Black (1962), Johansen (1980), Ost (1987) and others identify the theoretical model as a subcategory within the larger models framework. Miller (1978) includes models in words, numbers and systems as one of several subgroups, and writes that:

> A verbal theory which not only describes observations accurately, but also presents an

explicit account of how a system is believed to work can be accepted as a conceptual system isomorphic to a given concrete system.

A verbal theory, in other words, is a model of a concrete system. Therefore the theoretical statement that "all fire engines are red" contains conceptual elements corresponding to our perceptions of external objects, attributes and relationships. More proximately, the proposition that "evolution has a genetic basis" is a formal model uniting the concepts of evolution and genes, which themselves are ideas constructed from research models.

Models and the nature of science

As a subgroup, theoretical models possess the characteristics of models in general, and this attribute may be useful in explaining the structure of scientific knowledge.

Multiplicity. It has been observed that several models may accurately portray a phenomenon, and each, based on different assumptions and goals, may be accurate in its own right (Ashby, 1970). Similarly, theories may be developed based on different assumptions and to serve different purposes. It is thus appropriate to question the application of a single theory to all possible instances of an event, because no two events are exactly alike. Alternatively, one event may be adequately explained by several theories for different purposes. Understanding this principle may help students and practitioners develop tolerance and perspective. They may also become more sensitive to the importance of examining the assumptions of a theory before accepting or rejecting it.

Simplification. The construction and testing of a model of any system typically involves simplification and loss of information (Ashby, 1970). Scientists and technologists, as well as the users of scientific knowledge, may make serious mistakes when they overlook this principle and improperly apply a simple finding to a complex system. Defining a theory as a model reinforces the concept of research as artificial, and helpts to explain the reductionism that accompanies theory-building.

Tentativeness. Because models are based upon a limited set of assumptions, they are susceptible to change when assumptions change. Theoretical models are likewise tentative. Since a model is an artificial representation of a particular system, generalization or transfer of relationships to other systems will necessarily carry risks of error.

Lability and Refinement. Models are refined by adding, deleting, replacing, generalizing and differentiating their

parts (Stevens & Collins, 1980). The goodness or badness of a model is determined by its fit to the system it is intended to represent (Black, 1962). The goodness of a model also depends upon its capacity to be verified (Johansen, 1980), a process which depends upon its observed realtionship to other systems. Research is a process of construction and verification, and learning "...is largely a process of refining models [theories] so that they correspond better with the real world" (Stevens & Collins, 1980) or until they are consistent within the knowledge structure.

Model building - and research, using the proposed operational definition - involves looping between active data collection and modification of the model. At the same time, there is an evaluative looping taking place between assessment and continued development (after Morris, 1970). Within this series of processes, thinking requires the employment of models and the assessment and analysis of the adequacy of the model (Johansen, 1980). Factors to be considered in the evaluation of a new model - and theory - include its relatedness to accepted models; transparency, or ease of interpretation; robustness, or sensitivity to changes in assumption; fertility or predictivity; and ease of enrichment. It is difficult to dismiss the parallels between these criteria and those used to assess scientific knowledge: the similarity is taken here as validation of the conceptualization proposed.

Predictivity. Scientific knowledge is a network of predictive theoretical models with varying degrees of fit within a more general knowledge framework. The criterion of predictivity is based upon the assumption that real or perceived knowledge is part of a relatively stable and interrelated structure. Predictivity not only implies that one model leads to another, but also that the models are consistent among themselves. Consistency, in fact, is the only criterion possible when dealing with models of truely unexplored phenomena. It is this characteristic which distinguishes the models of science from those of other domains.

Application to Education

The working definition of science as a body of knowledge has, in the last several decades, begun to give way to a more process-oriented approach. Intensive use of process skills, however, may not lead to a good understanding of the nature of knowledge nor to the flexibility of thought and reasoned judgement we might wish our students to have. In view of our desire to educate for literacy, rather than professional practice, research into alternative conceptualizations of science is essential.

The operational definition of science as the building predictive models is the primary concern of this paper. It developed from an interest in the role of analogies in science, and was used informally by the author, in 1985 and again in 1987, to organize instruction in two university introductory biology classes. The approach received unanimous support from students in written evaluations at the end of the respective semesters (Gilbert, 1987b). Students reported that the approach gave them a better understanding of the organization and purpose of science than they felt they had received in previous classes. However, it is not possible to make definitive statements about the effectiveness of the approach because of many uncontrolled variables.

The present study was undertaken to determine whether students possess such valid knowledge of models and, if so, whether this knowledge is related to characteristics of constructivist science. It was intended merely to point the way toward potentially fruitful new research. The specific objectives were:

1. To obtain descriptive undergraduate student responses to five statements describing the nature of science and scientific knowledge;
2. To obtain descriptive responses to similarly-worded statements describing the nature of models and model-building.
3. To identify general patterns of response in both conditions that might be of significance to science educators.
4. To compare students' beliefs about models to those they hold about science in order to evaluate the potential for transfer of beliefs from one to the other.

Design and Procedures

Subjects

The subjects were 687 undergraduate students in a lecture biology course at a large public university in the Southwest. The majority were freshmen (59%), female (52%), and averaged 19.8 years of age. Most were taking their first university science course, and did not intend to pursue a career in science. They had an average of 2.4 years of high school science experience. There was no reason to believe that these students were not typical of the target population in general.

Instruments and procedure

In order to determine students' beliefs, two parallel sets of six statements were prepared. One set dealt with the nature of scientific knowledge and processes, and the second with the nature of models and model building. These statements were written in the format of items on the Views on Science-Technology-Society (VOSTS) instrument (Aikenhead, 1987; Aikenhead, Fleming & Ryan, 1987), with content based on items from the Nature of Science Knowledge Scale (NSKS) of Rubba and Anderson (1978). Each of the six items in each set was related to a different assumption about science. These assumptions were that (1) error is an accepted part of research; (2) methodology must follow from the intent of the scientist; (3) theories and concepts of the various sciences interact to form a unified structure; (4) science is intuitive and creative as well as logical; (5) scientists will be influenced in their views by their social environment; and (6) scientific knowledge is artificailly constructed by humans to describe and predict from their external environment. These assumptions seem to most closely describe constructivist science, although some underlie logical positivism as well.

The modified statements pertaining to science were:

(a) In order to be acceptable, scientific knowledge must contain no errors.
(b) The best scientists will be those who follow the same scientific method, whatever the problem.
(c) The laws, theories and concepts of biology, chemistry and physics interact with each other.
(d) Scientific work is a logical process, rather than intuitive or creative.
(e) The social environment of a scientist will not influence the content of the knowledge he or she proposes.
(f) Scientific knowledge is artificial and does not show nature as it really is.

The alternative set of statements had similar wording, but was designed to assess the student's beliefs about models and model building. These statements were:

(a) In order to be acceptable, a model of an object or event must contain no errors.
(b) People who are best at building models will use the same approach, whatever the problem.
(c) The models constructed in biology, chemistry and physics interact with each other.
(d) Building models is a process which is logical, rather than intuitive and creative.

(e) The social environment of a model builder will not influence the content of the model he or she constructs.
(f) A model of an object or event is artificial, and does not show the object or event as it really is.

Each of these statements was printed separately on a half-sheet of paper. Instructions were identical to those used on the VOSTS (Aikenhead, Fleming and Ryan, 1987). Students were asked to respond to an item by checking whether they agreed with it, disagreed, or couldn't tell, and to justify their response in a 2-5 sentence statement. The instruments were assorted uniformly in order to insure an adequate number of responses for each statement and were given to 8 of the 14 available class sections by four different instructors. All of the statements received 42 to 67 responses, with a mean of 57. No instruction had been given on the nature of science or scientific process in any of the classes prior to the administration of this instrument.

Results

Six hundred and eighty-four statements were received and reduced by the investigator to a manageable number of descriptive propositions. Each statement was then reviewed a second time in order to rematch it to an appropriate proposition. Some students indicated that they did not understand the item, or wrote statements which could not be usefully reported in the Tables. These are generally consolidated as unusable or unique responses.

Knowledge of Science

Students substantially disagreed (60%) with the statement that "scientific knowledge is artificial and does not show nature as it really is" (Table 1). They commonly expressed the belief that nature is accurately portrayed and that knowledge is not an artificial construct. Fact and research were cited by 26% of the students as the basis for their belief that nature was portrayed in reality. A small number (7%) felt that while theories are artificial, facts are not. Only 3 students (5%) expressed the idea that knowledge is a constructed entity which does not show nature as it truely is. It seems clear that the majority of students accept the view of the objective realists that reality is truely discoverable. It also appears from these results that some students do not readily distinguish between the concept of knowledge and their perceptions of relationships in the external world.

Over one-quarter of the respondents (26%) believed that acceptable scientific knowledge should have no errors (Table 3). Most students (58%) appeared to recognize that error was an inevitable part of scientific work. Around one-quarter (26%) stated that errors were a necessary part of science because scientists, like most people, learn from error and are thus led in more productive directions. These results indicate that most students overtly accept the tentative nature of science. There were indications that a large percentage of the agreement was based on a generalized belief that error is a part of all human activities.

A majority of students (57%) agreed that the laws, theories and concepts of biology, chemistry and physics interact with each other (Table 5). A substantial minority (20%) felt that they could not respond because they had not had one or more of the subjects in school. Only 11% disagreed with the statement.

Most students (58%) agreed that scientific work requires intuition and creativity as well as logic (Table 7). However, 30% accepted the idea that logic was most important, with 17% supporting this choice by equating logic with fact and research. While this indicates a general awareness of the creative nature of science, almost one-third of the students still accept the stereotype of that science requires little intuition or creativity. Moreover, it seems clear that fact and research are, for some students, equated with logical thought.

A small majority of students (60%) accepted the idea that scientists are influenced by their social environment (Table 9), although there was a tendency for them to use the terms environment and social environment interchangeably. Their statements appeared to stem from a general assumption that people cannot avoid being influenced by their surroundings. Only 12% seemed to accept the notion that scientists are somehow isolated from such influences.

The same deductive reasoning also led a majority (79%) to express their faith in the benefits of flexibility by disagreeing that the best scientists follow the same scientific method for every problem (Table 11). As in the case of social environment, this pattern of response seemed to flow from a more general belief in the value of diversity and flexibility.

Knowledge of Models and Model-building

One of the significant findings of this research is the relative confusion students display when asked about the nature of models. Models are important devices, even in traditional science, yet many students appear to have a narrow and incomplete conception of both models and model-building. This was evident by the number of students

who appeared make their decisions using a scale model protoytpe, and who responded with generalized indirect statements.

A small majority (56%) of the students believed that a model is an artificial representation which gives one an idea of an object or event but does not show it as it really is (Table 2). An additional 8% believed that a model is artificial, but actually shows an object or event as it is. The remaining 15% disgreed with the statement. Some of these students indicated their misunderstanding of artificiality as falseness, rather than as a product of human manufacture. It was feared that this misinformation might distort the results, but this did not appear to be the case in the majority of cases. The results are believed valid for purposes of comparison. The idea that a model is an artificial construct seems fairly well established in the students' minds.

Only 27% of the students stated that models should contain no errors. A 60% majority agreed in essence that errors are to be expected (Table 4), although 16% qualified this by saying that the acceptablility of an error depends upon its nature and extent.

When asked whether the models produced in biology, chemistry and physics interact with each other, 39% said that they did, 9% that they did not, and 22% responded that they had not studied enough science to know (Table 6). In this case, 6% expressing uncertainty about what a model is, and 8% said that it depended on the model. The confusion apparent in these responses may be attributable to the limited conceptualizations of models held by the students.

Creativity and intuition were accepted as a part of model-building in 45% of the usable responses, while 10% believed that model building was almost entirely logical (Table 8). The idea that some students were reasoning with a scale model prototype was supported by the fact that 12% of the respondents stated that a model was a replica and required no creativity to build. It is not improbable that this idea is held by a significantly greater number of students than actually expressed it.

When students were asked to respond to the statement that the social environment will influence the content of a model (Table 10), 66% responded that it would. An additional 5% implied that the environment would determine the models' usefulness and thus would perhaps be influential. Only 3 individuals (5%) felt that the model builder would not be at all influenced by these external factors.

The use of a variety of approaches to build models was supported by 37% of the students (Table 12). An additional 25% hinted that a consistent approach was important to solving a problem, but did not deal directly with model-

building in their answer. In this case, it was difficult to determine their actual thinking. Only 9% actually stated that models should be built using an inflexible approach.

Comparing Model-building to Science Process

There are substantial differences in the response patterns of statements from the two conditions addressing the criterion of artificiality (Tables 1 and 2). While only 5% of respondents agreed that scientific knowledge is artificial, and does not show nature as it really is, a majority (56%) agreed that a model of an object or event possesses these characteristics. This is considered a more desirable response, since the theoretical basis of this assumption is the differentiation of knowledge as a human construct from actual relationships that may 'exist in the external environment (Glasersfeld, 1985). These relationships are unprovable in any absolute sense (Norner and Rubba, 1978). Since knowledge is constructed, it is artificial by definition. It appears that defining science as a model-building process could be an effective way to bring students to understand this distinction between knowledge and perception. Properly used, the concept of the theoretical model might have an associated artificiality and tentativeness not associated with the concepts of knowledge or theory. However, it is apparent that students do not come to the classroom with a firm understanding of models, and that their misconceptions could cause more harm than good unless they are modified.

The general patterns of response were similar for statements reagrding the acceptance of error (Tables 3 and 4). Most students accepted the idea that both scientific knowledge and models will contain error, although their reasoning was diverse and not overtly the same for knowledge as for models. Because of the differences, some benefit might be realized from the models approach. The ideas that the acceptability of error depends upon the extent of the error and purpose of the model, and that models are intended to give us an idea of a thing (Table 4) are both capable of adapatation to explain the nature of science. Adoption of a models paradigm to the purpose of science education could provide for transfer of these conceptions without the loss of the desirable beliefs stated in both conditions.

From Tables 5 and 6, it is apparent that a majority (57%) of the students agreed that the laws, theories and concepts of the various sciences interact, while only 39% said that there was a unity among the models constructed in the different disciplines. One reasonable interpretation of this response pattern is that students perceived models as relatively discrete entities - in all probability as scale models - which seem to have little relationship to each

other across the various fields of study. A leaf model, for example, is not likely to seem closely related to a molecular model in chemistry.

Because of the resulting confusion, the models statement (Table 6) drew a greater number of ambiguous responses. However, in both conditions about one-fifth of the students responded that their limited school science background prevented them from knowing. This supports the notion that traditional divisions act against the unity that should characterize science. The proposed operational definition is not likely to have much effect on this problem, and in fact could exacerbate it. It is apparent is that the students' conceptualization of models needs to be expanded in order to avoid adding to the problems that confront science educators.

The result of a limited conceptualization of models is also apparent in response to statements that scientific work/model building is logical rather than intuitive and creative (Tables 7 and 8). Most students (58%) realized that some creativity and intuition is necessary for science, although a rather significant percentage agreed that logic is primary. A smaller percentage (45%) thought of model-building as intuitive or creative. Twelve percent stated outright that a model was a replica requiring no creativity to build. It is not improbable that others held this same, but unstated, view. The relatively high percentage of unique and unusable responses reinforces the inference that students do not have a strong conceptualization of models.

Tables 9 and 10 indicate that students have similar opinions about the influence of the social environment in both science and model-building. The response pattern seems to center around the general idea that the social environment influences everything that people do. One confounding variable in this case was a misunderstanding of the term "social environment" as opposed to "environment" in general. References were made to several kinds of environment, including professional surroundings. Since there is so little difference between conditions, it is felt that the proposed operational definition would have little effect on this variable.

The response patterns in Tables 11 and 12 are interesting, if only because there is such a variety of justifications given under both conditions. Many of the statements made by the students seem to relate more to their conception of problem-solving than to the items themselves. It might be expected that respondents who are uncertain will given more generalized statements than those who are certain of their knowledge. This seems to be more the case for model-building (Table 12) than for scientific method (Table 11).

Summary

In reviewing the above results, several conclusions are apparent. First, it appears that the use of a models operational definition to describe science could enhance scientific literacy by providing students with a general structure for understanding the processes and products of the field. This structure appears to be consistent with the constructivist approach to knowledge and has the potential to be more highly explanatory than available definitions as reflected in current textbooks. The nature of knowledge as a constructed entity is particularly apparent promoted with the adoption of this definition. However, the value of the conceptualization depends heavily upon the development of the students' knowledge and support of a broad definition of models. This understanding is a desirable goal in and of itself.

It is apparent that students do not have a strong grasp on the models concept. Even if one is unwilling to accept the constructivist viewpoint, the importance of models to traditional scientists has been well documented (Black, 1962; Hempel, 1965; Leatherdale, 1974) and should be an integral part of students' knowledge. The creation of a model is the focal purpose of the application of concept learning and process skill development, yet some freshmen college students state that they do not know what a model is.

It is likely that a models framework could be integrated into a curriculum with minimal use of instructional time. Previous informal application of this approach by the author indicates that students pick up the necessary concepts and relationships rapidly. Whether this results in demonstrably better understanding of science has not been determined, but it is certain that students feel positive about the approach and support its use.

Future research should be designed to sharpen the focus of this work. It is important to identify those criteria which can be better explained with a new operational definition, and to find how the definition may need to be refined. As it is, it is felt that defining science as the building of predictive models has the potential to focus instruction, to result in greater understanding of science and the scientific knowledge structure, and thus to contribute to the achievement of nationally recognized goals.

References

Aikenhead, G.S. (1987). High school graduates' beliefs about science-technology-society. III. Characteristics and limiations of scientific knowledge. Science Education, 71, 459-488.

Aikenhead, G.S., Fleming, R.W. & Ryan, A.G. (1987). High school graduates' beliefs about science-technology-society. I. Methods and issues in monitoring student views. Science Education, 71, 145-161.

Ashby, W. (1970). Analysis of the system to be modeled in The process of model building in the behavioral sciences. ed. by R. Stogdill. New York: W.W. Norton & Co.

Barber, B. (1961) Resistance by scientists to scientific discovery. Science, 134, 596-602.

Black, M. (1962). Models and metaphors. Ithaca, NY: Cornell University Press.

Coleman, W., & Selby, C. (1983). Educating Americans for the 21st Century. Report to the National Science Board Commission on Precollege Education in Mathematics, Science and Technology. Washington, DC: The National Science Foundation.

Clark, M.E. & Holler, L.D. (1986, Sept/Oct). Teaching science within the limits of science. Journal of College Science Teaching, 8-57.

Fensham, P. (1983). A research base for new objectives of science teaching. Science Education, 67, 3-12.

Gilbert, S. (1987a). Model building: a suggestion for a theoretically consistent definition of science for classroom use. (unpublished manuscript).

Gilbert, S. (1987b). Using the model concept as an organizer for explaining science: preliminary report on its effects. (unpublished manuscript).

Glasersfeld, E. (1985). Reconstructing the concept of knowledge. Archives de Psychologie, 53, 91-101.

Gould, S. (1987, October). Justice Scalia's misunderstanding. Natural History, 14-21.

Hempel, C. (1965). Aspects of scientific explanation. New York: The Free Press.

Johansen, G. (1980). Analogue models in the laboratory exercise: one method for teaching to think. Paper presented at the meeting of the National Association for Research in Science Teaching. April, 1980.

Kerlinger, F. (1973). Foundations of behavioral research. New York: Holt, Rinehart & Winston.

Kuhn T.S. (1970). The structure of scientific revolutions. (2d Ed). Chicago: The University of Chicago Press.

Leatherdale, W. (1974). The role of analogy, model and metaphor in science. Oxford: North Holland Publishing Co. Ltd.

Mahoney, M.J. (1979). Psychology of the scientist: An evaluative review. Social Studies of Science, 9, 349-375.

Merton, R.K. (1969). Behavior patterns of scientists. American Scientist, 57, 1-23.

Miller, J. (1978). Living systems. New York: McGraw-Hill Book Company.

Miller, R. (1984). Science teaching for the citizen of the future. Science Education, 68, 403-410.

Morris, W. (1970). On the art of model building. in The process of model building in the behavioral sciences. ed. by K. Stogdill. New York: W.W. Norton & Co.

Norner, J.K. & Rubba, P. (1978, January). The myth of absolute truth. The Science Teacher, 29-30.

Osborne, R.J. & Wittrock, M.C. (1983). Learning science: a generative process. Science Education, 67, 489-508.

Ost, D. (1987). Models, modeling and the teaching of science and mathematics. School Science and Mathematics, 87, 363-370.

Roe, A. (1961). The psychology of the scientist. Science, 134, 456-459.

Rubba, P. & Anderson, H.O. (1978). Development of an instrument to assess secondary school students' understanding of the nature of scientific knowledge. Science Education, 62, 449-458.

Sellitz, C., Wrightsman, L. & Cook, S. (1976). Research methods in social relations, 3d Ed. New York: Holt, Rinehart & Winston.

Stevens, R., & Collins, A. (1980). Multiple conceptual models of a complex system, in Aptitude, learning and instruction, vol. 2. ed. by R. Snow, P-A Federico, & W. Montague. Hillsdale, NJ: Lawrence Erlbaum Associates, inc.

Wagner, P. (1983). The nature of paradigmatic shifts and the goals of science education. Science Education, 67, 605-613.

Table 1.

Statement 1: Scientific knowledge is artificial and does not show nature as it really is.

Statement	n	freq.
GENERALLY AGREE.....	3	5%
Scientific knowledge is something that is made up by scientists. Because it changes, we don't know for sure what nature is.	3	5%
GENERALLY DISAGREE.....	39	67%
Scientific knowledge is not artificial. We study it. It shows nature as it is.	18	31%
Scientific knowledge is not artificial because it is based on observation, fact and experiment.	15	26%
The factual part of knowledge is not artificial but this is not true for theories.	4	7%
Science knowledge is not artificial because it permits us to do things and progress.	2	3%
UNUSABLE OR UNIQUE RESPONSES.....	16	28%
	N = 58	

Table 2.

Statement 2: A model of an object or event is artificial and does not show the object or event as it really is.

Statement	n	freq.
GENERALLY AGREE.....	34	56%
Models are imitations. They give an idea of something but do not show things as they really are.	34	56%
PARTLY AGREE.....	5	8%
A model is artificial but shows an object or event as it really is.	5	8%
GENERALLY DISAGREE.....	9	15%
A model is not artificial because it approximates a real thing.	7	12%
Models cannot be artificial because they are useful to those who make them.	2	3%
UNUSABLE OR UNIQUE RESPONSE.....	13	21%
	N = 61	

Table 3.

Statement 3: In order to be accepted, scientific knowledge must contain no errors.

Statement	n	freq.
GENERALLY AGREE.....	11	26%
Scientific knowledge should have no errors. We need to know the right answers for learning and application to be sound.	11	26%
GENERALLY DISAGREE.....	24	58%
Science should be as accurate as possible but perfection is not a realistic expectation.	5	12%
Scientific knowledge will have errors, but these will be corrected over time.	4	10%
Errors are necessary in order for us to learn more. We learn from our errors.	11	26%
There will always be errors in scientific knowledge because it is always changing.	4	10%
UNUSABLE OR UNIQUE RESPONSE.....	7	16%
	N = 42	

Table 4.

Statement 4: In order to be accepted, a model must contain no errors.

Statement	n	freq.
GENERALLY AGREE.....	18	27%
Models should have no errors because they will then be misleading and unusable. They will not be the same object or event.	18	27%
GENERALLY DISAGREE.....	41	60%
The acceptability of error depends upon the extent of the error and the purpose of the model.	11	16%
Models are not perfect. They are just to give one an idea of a thing.	7	10%
Errors are necessary in order for us to learn more. We learn from our errors.	2	3%
Nothing is perfect. A perfect model is an unrealistic expectation.	21	31%
UNUSABLE OR UNIQUE RESPONSE.....	8	12%
	N = 67	

Table 5.

Statement 5: The laws, theories and concepts of biology, chemistry and physics interact with each other.

Statement	n	freq.
GENERALLY AGREE	32	57%
They interact because they use similar terms, concepts and principles.	23	41%
They interact because they are all a part of science and use similar methods.	7	12%
They interact because everything interacts with everything else.	2	4%
GENERALLY DISAGREE	6	11%
They do not interact because they study different things. They are different subjects.	6	11%
OTHER	11	20%
Don't know because haven't studied enough of the various fields in school	11	20%
UNUSABLE OR UNIQUE RESPONSES	7	12%
	N = 56	

Table 6.

Statement 6: The models of biology, chemistry and physics interact with each other.

Statement	n	freq.
GENERALLY AGREE	25	39%
They interact because they use similar terms, concepts and principles.	17	26%
They interact because they are all a part of science and use similar methods.	7	11%
They interact because everything interacts with everything else.	1	2%
GENERALLY DISAGREE	6	9%
They do not interact because they portray different things. They are different subjects.	6	9%
OTHER	23	36%
Don't know, because haven't studied enough of the various fields in school	14	22%
Depends upon the kind of model	5	8%
Don't know what a model is	4	6%
UNUSABLE OR UNIQUE RESPONSES	11	17%
	N = 65	

Table 7.

Statement 7: Scientific work is a logical process rather than intuitive and creative

Statement	n	freq.
GENERALLY AGREE.....	16	30%
Science is organized logically and requires that a systematic procedure be followed.	4	7%
Science is based on fact and research and is therefore mostly logical.	9	17%
Science is logical. Creativity is not helpful in looking for reasons behind something.	3	6%
GENERALLY DISAGREE.....	31	58%
Creativity, intuition and logic are all required in science.	20	37%
Science is more intuitive and creative than logical.	2	4%
Science is mostly logical but creativity and intuition are needed for new ideas and insight.	9	17%
UNUSABLE OR UNIQUE RESPONSE.....	7	12%
	N = 54	

Table 8.

Statement 8: Building models is a process that is logical rather than intuitive and creative.

Statement	n	freq.
GENERALLY AGREE	6	10%
Building models is almost entirely logical.	2	3%
Models are logically built because they are used to prove the logic of an argument.	4	7%
GENERALLY DISAGREE	26	45%
Building models is intuitive and creative.	6	10%
Building models is intuitive and creative rather than logical.	5	9%
Building models is intuitive and creative as well as logical.	12	21%
Building models is more logical than intuitive and creative, though these are important.	3	5%
OTHER	7	12%
A model is a replica and requires no creativity to build	7	12%
UNUSABLE OR UNIQUE RESPONSES	19	33%
	N = 58	

Table 9.

Statement 9: The social environment of a scientist will not influence the content of the knowledge he or she proposes.

Statement	n	freq.
GENERALLY AGREE.....	6	12%
The scientist should be in control so the environment will have little influence on the knowledge proposed.	6	12%
GENERALLY DISAGREE.....	31	60%
Everyone is influenced by the social environment, so the scientist will be too.	22	42%
The scientist will be influenced. The environment is where observations come from.	4	8%
Social contacts with other scientists will be relevant and important to the scientist.	5	10%
UNUSABLE OR UNIQUE RESPONSES.....	15	28%
	N = 52	

Table 10.

Statement 10: The social environment of a model builder will not influence the content of the model which he or she constructs.

Statement	n	freq.
GENERALLY AGREE.....	3	5%
The model builder will be individually motivated and will not be influenced by the social environment.	3	5%
GENERALLY DISAGREE.....	39	66%
Everyone is influenced by the social environment. The model builder will be too.	35	59%
The social environment may have some effect but the individual's intentions are most important.	4	7%
OTHER.....	3	5%
The model will serve the needs of those in the environment and they will determine the model's correctness.	3	5%
UNUSABLE OR UNIQUE RESPONSES.....	14	24%
	N = 59	

Table 11.

Statement 11: The best scientists will be those who follow the same scientific method, whatever the problem.

Statement	n	freq.
GENERALLY AGREE.....	6	11%
A uniform approach will be more consistent and best for science.	6	11%
GENERALLY DISAGREE.....	45	79%
The best scientists will develop new methods to solve a problem.	11	19%
The best of anything requires diversity and flexibility - different approaches are needed for progress.	11	19%
A scientist will work best using his or her own methods rather than someone else's.	4	7%
Different problems require different solutions.	10	18%
There may be more than one answer to a problem and different methods will provide a better solution.	7	12%
Science is experimental. Part of science is discovery, including of new methods.	2	4%
UNUSUAL OR UNIQUE RESPONSE.....	6	11%
	N = 57	

Table 12.

Statement 12: People who are best a building models will use the same approach, whatever the problem.

Statement	n	freq.
GENERALLY AGREE	5	9%
Models should be built using a set approach.	5	9%
GENERALLY DISAGREE	21	37%
The best of anything requires diversity and experiment.	3	5%
The nature of the problem will determine the approach that is used.	9	15%
Because people approach their problems differently, their models will not be built in the same way.	9	15%
OTHER	14	25%
People should use the approach they are used to, because this will lead to the best solutions.	5	9%
The best people will always approach a problem by thinking it through and getting the whole picture.	4	7%
People tend to stay with a successful approach.	5	9%
UNUSABLE OR UNIQUE RESPONSE	18	31%
	N = 58	